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Effects of water temperature and flavoring on fluid consumption were studied in fourteen unacclimatized males (21-33 yrs) during 6h of treadmill exercise (4.8 $km.h^{-1}$, 5% grade for 30 $min.h^{-1}$) in a hot environment. Subjects consumed each of four iodinated (16 $mg.L^{-1}$) beverages (15°C water, 40°C water, 15°C raspberry-flavored water and 40°C raspberry-flavored water) on four non-consecutive days. We identified two groups of individuals by body weight (BW) loss during the cool water trial: drinkers (D) who lost less than 2% initial BW (0.44-1.46%) and reluctant drinkers (RD) who lost more than 2% (2.26-2.83%). D consumed 31% more cool water (3.29 $\pm$ 0.22 L) (mean $\pm$ SEM) than RD (2.51 $\pm$ 0.15 L) and experienced smaller BW losses (0.80 $\pm$ 0.15%) relative to RD (2.53 $\pm$ 0.12%). Warm water reduced 6h consumptions in both D (2.07 $\pm$ 0.38 L) and RD (1.04 $\pm$ 0.30 L) and also increased BW loss (2.33 $\pm$ 0.40 % and 3.90 $\pm$ 0.41 %, respectively). Flavoring enhanced warm water consumption (1.86 $\pm$ 0.22 L) and reduced BW loss (3.30 $\pm$ 0.28 %) in RD only. Reduced consumption of warm water increased rectal temperature, heart rate and plasma osmolality in both groups.

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PALATABILITY OF DRINKING WATER: EFFECTS ON VOLUNTARY DEHYDRATION

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Running head: Enhancing Fluid Consumption

ABSTRACT

SZLYK, P.C., I.V. SILS, R.P. FRANCESCONI, R.W. HUBBARD AND L.E. ARMSTRONG. Palatability of Drinking Water: Effects on Voluntary Dehydration. PHYSIOL.BEH. Effects of water temperature and flavoring on fluid consumption were studied in fourteen unacclimatized males (21-33 yrs) during 6h of treadmill exercise ($4.8\ km \cdot h^{-1}$, 5% grade for $30\ min \cdot h^{-1}$)in a hot environment. Subjects consumed each of four iodinated ($16\ mg \cdot L^{-1}$) beverages (15°C water, 40°C water, 15°C raspberry-flavored water and 40°C raspberry-flavored water) on four non-consecutive days. We identified two groups of individuals by body weight (BW) loss during the cool water trial: drinkers (D) who lost less than 2% initial BW (0.44-1.46%) and reluctant drinkers (RD) who lost more than 2% (2.26-2.83%). D consumed 31% more cool water (3.29 $\pm$ 0.22 L) (mean $\pm$ SEM) than RD (2.51 $\pm$ 0.15 L) and experienced smaller BW losses (0.80 $\pm$ 0.15 %) relative to RD (2.53 $\pm$ 0.12 %). Warm water reduced 6h consumptions in both D (2.07 $\pm$ 0.38 L) and RD (1.04 $\pm$ 0.30 L) and also increased BW loss (2.33 $\pm$ 0.40 % and 3.90 $\pm$ 0.41 %, respectively). Flavoring enhanced warm water consumption (1.86 $\pm$ 0.22 L) and reduced BW loss (3.30 $\pm$ 0.28 %) in RD only. Reduced consumption of warm water increased rectal temperature, heart rate and plasma osmolality in both groups.

Index terms: Dehydration, voluntary dehydration, fluid consumption, flavoring, temperature regulation, palatability.

INTRODUCTION

Voluntary dehydration occurs when an individual does not adequately rehydrate through drinking although fluids are plentiful and readily available. Adolph and coworkers [21] have shown that voluntary dehydration in man increases when work load and/or environmental temperature increases, when the temperature of drinking water is increased or its palatability decreases, and when inadequate time is allotted for "retanking". Because environmental temperature and workload are often difficult to control, two critical factors which may affect fluid intake and voluntary dehydration are water temperature and palatability.

While animal studies have demonstrated that the preferred drinking water temperature is that which is near normal body temperature (30^{o}-37^{o}C) [5,7,9], the preferred temperature for consumption in human adults is close to 15^{o}C (range 10^{o}-20^{o}C) as measured by fluid intake and palatability ratings [2,5,6,22]. While very cold water received better hedonic ratings, subjects frequently ingested less 5^{o}C than 15^{o}C water [5,6] particularly when large volumes had to be consumed to avoid dehydration. To be palatable, drinking water should be clear, colorless, tasteless, odorless, cool and aerated [14,24]. While this water may be pleasant to drink, it may not always be potable, and in many cases must be disinfected to destroy disease producing organisms.

In many military situations, individual troops must acquire water, treat it with iodine, and then consume it at sometimes elevated ambient temperature. However, despite unpalatable components in the drinking water, increased fluid consumption may be elicited through the addition of flavorings [14,22]. Two hypotheses have been advanced to explain why man does not always adequately rehydrate although water is plentiful and palatable. The first theory contends that voluntary dehydration occurs because the thirst mechanism fails to fully assess the degree of fluid deficit and fails to stimulate adequate drinking to compensate for the dehydration [1,21]. In certain situations, drinking by command is the only solution to this problem. The second hypothesis suggests that voluntary dehydration is the result of a negative alliesthesia, or the intervention of an unpleasant stimulus while drinking [6,14,20]. The term "alliesthesia" was used initially by Cabanac [6] to describe the phenomenon whereby a stimulus could either be pleasant (thereby facilitating the return to a normal state) or unpleasant depending upon the internal status of the subject. If such a strong behavioral component is present, then other practical interventions such as cooling, flavoring or coloring might be employed to increase consumption.

The present investigation was designed to assess the effects of water temperature and flavoring on voluntary dehydration in young adult males during a prolonged walk under simulated desert conditions. Warm iodine-treated water, having been determined to result in diminished consumption in prior experiments [14], was considered a source of negative alliesthesia during work-induced hyperthermic states.

METHODS

Subjects: Fourteen young, unacclimatized men (21-33 years of age) who were selected for age, lack of experience in water balance studies and availibility served as test subjects in this study. Subjects were briefed on the experimental design, testing procedures and medical risks, but the importance of the body weight and *ad libitum* water consumption measures was not emphasized. The volunteers signed statements of informed consent and retained the right to withdraw from the study at any time without retribution.

<u>Protocol:</u> Subjects spent 6 h in a climatic chamber set to desert-like conditions (40°C db, 28.5°C wb and 8.1 $km \cdot h^{-1}$ windspeed) on each of 4 nonconsecutive days between mid-November and mid-January. As suggested by Sohar [22] and others [1,12,21], and implemented during our previous studies [3,14], work/rest cycles of 30/30 min were selected to insure sufficient time for drinking during the rest periods. This design also enabled us to assess intake when work was not a behavioral variable. The exercise consisted of treadmill walking (5% incline, 4.8 $km \cdot h^{-1}$) for 30 $min \cdot h^{-1}$ for 6 h; during the remainder of each hour, subjects sat comfortably. Thus, if the six work cycles were completed, each subject would walk 14.5 km and would climb 724 m.

All water was initially treated with iodine tablets (16 $mg \cdot L^{-1}$) to simulate normal field pick-up water. Although artificially sweetened, the raspberry flavored beverage powder had low carbohydrate (9.32 $g \cdot L^{-1}$) and caloric content (39 $kcal \cdot L^{-1}$) and minimal halogen (iodine, chlorine) demand, making it compatible with the iodine-treatment. Each subject participated in each of four (4) randomized trials which differed in the beverage available for drinking during the 6 h in the chamber:

Trial 1. Iodine (I_2) treated (16 $mg \cdot L^{-1}$) cool (15°C) water

Trial 2. I_2 treated warm (40°C) water

Trial 3. I_2 treated cool raspberry flavored water

Trial 4. I_2 treated warm raspberry flavored water

Throughout the experiment, drinking was <u>ad libitum</u> and the beverage was continuously provided in a coded canteen placed within comfortable reach of each subject. The order of the four trials and subject grouping (4 subjects per treadmill) were randomized and carried out in a double blind fashion.

<u>Measurements:</u> Following a breakfast of cereal, milk, toast, and juice at 0630h, subjects proceeded to a dressing room. After voiding, each subject was weighed nude (Sauter, ±10 g). To insure adequate hydration, urine

specific gravity was tested and each subject was required to drink 250 ml of water prior to the start of data collection. Subjects were fitted with standard ECG leads, a 3 point (chest, arm, leg) thermocouple skin temperature harness and a rectal probe (inserted to a depth of 10 cm). Subjects wore shorts, socks, and sneakers for the test and were reweighed prior to initiation of the trial to obtain a combined clothed and instrumented weight.

Subjects entered the climatic chamber and remained standing for 20 min after which a baseline (PRE) venous blood sample was drawn. Heart rate and rectal and skin temperatures were recorded prior to exercise and these variables were continuously monitored at 4 min intervals for the duration of the experiment. Additionally, subjects were weighed within 3 min of the start and completion of each 30 min exercise bout.

Fluid intake was continuously monitored by weighing (Sartorius 1403-M70; $\pm$1g) the canteens at each 30 min interval. Lunch, consisting of typical Army rations (Meal, Ready to Eat) weighed to the nearest gram, was provided at the end of the 3rd exercise bout (2.5-3.0 h). After the 2nd and 6th exercise, subjects remained standing for 20 min to obtain additional blood samples. Following a final clothed and instrumented body weight, subjects re-entered the tropical dressing room, removed their clothing and a final nude weight was obtained.

Plasma volume changes following the 2nd and 6th exercise bout were calculated as the percent change from the pre-exercise sample using hematocrit (corrected for trapped plasma) and hemoglobin concentration [8]. Hemoglobin was determined using a commercial kit (Cyanomethemoglobin method; Hycel) and hematocrit was measured using the microhematocrit technique. Additionally, serum from all three blood samples was analyzed for electrolytes (Radiometer Copenhagen FLM-3 flame photometer), osmolarity (Osmette; Precision Instruments) and total protein (refractometer). All additional urine samples were analyzed for volume, specific gravity and osmolarity.

Upon completing each session in the chamber, all subjects were asked to rate their overall level of comfort after 6h in the heat. In addition, Environmental Symptoms Questionnaire (ESQ) results were received from only eight out of the fourteen subjects. The ESQ consisted of a total of 68 questions which were rated on a 6-point scale from "not at all" to "extreme", and reflected the subjects' perceptions of their condition following completion of the heat/exercise scenario.

Since the sensation of thirst is typically not sensed until the body has reached a fluid deficit of 2% [12,21], individuals who are able to maintain deficits below such levels are at a lesser risk of becoming casualties to heat illness due to dehydration. Based upon the criteria of a 2% loss of initial body weight (BW), our laboratory [24] has proposed classifying individuals who are able to maintain their BW loss at less than 2% during a 6h work/rest cycle desert protocol as DRINKERS (D). Individuals losing more than 2% from their initial BW during such a 6h scenario would be classified as RELUCTANT DRINKERS (RD). Subjects from this study were classified likewise and all data were analyzed using analysis of variance and paired t-tests. Reported values represent the mean $\pm$ standard error of the mean ($\bar{x} \pm$ SEM).

RESULTS

Figure 1 shows the distribution of body weight loss for the 14 subjects from this study. About 35% (5/14) of the subjects (Ss) lost more than 2% of their initial body weight (BW) (2.53 $\pm$ 0.12%) during the 6h protocol when cool (15^{o}C) water was provided ad libitum. These Ss were designated as RELUCTANT DRINKERS (RD) while the remaining 65% (9/14) were classified as

TABLE 1

PRE-EXERCISE PHYSIOLOGICAL VALUES

	N	AGE (yr)	BW (kg)	HEIGHT (cm)	HR (bpm)	Tre (°C)	Tsk (°C)	Uosm ($mOsm \cdot kg^{-1}$)	$U_{S.G.}$	P_{Na+} ($mEq \cdot L^{-1}$)	P_{K+} ($mEq \cdot L^{-1}$)	Posm ($mOsm \cdot kg^{-1}$)	HCT (%RBC)	HB ($g \cdot dl^{-}$
DRINKERS	9	24	81.4	182.5	89	37.02	35.53	941	1.024	141	4.7	293	45.2	14.3
		±1	±5.1	±3.3	±4	±0.06	±0.19	±36	±0.001	±1	±0.1	±1	±0 4	±0.3
RELUCTANT DRINKERS	5	25	80.5	177.3	85	37.01	35.35	925	1.024	143	4.6	293	44.7	14.4
		±1	±3.9	±2.6	±5	±0.06	±0.34	±123	±0.003	±1	±0.1	±1	±0.5	±0.2
								(4)*	(4)*					

1 Values are mean ± SEM for each measure based upon four (4) trials.

* N=4 subjects for these measures.

DRINKERS (D), since they were able to maintain BW loss at less than 2% (0.80±0.10 %) of initial BW. Table 1 demonstrates that D and RD were similar in age, physical characteristics, and pre-exercise heart rate (HR), rectal (Tre) and skin (Tsk) temperature, and plasma chemistries (Table 1, p=ns).

Fluid Consumption and Body Weight Loss: Fluid consumption is depicted in Figure 2 (top panel). During the cool water trial, RD consumed 2.51 ± 0.15 L (-24%) while D ingested 3.29 ± 0.22 L during the 6h of intermittent exercise ($p<0.025$). Differences in fluid intake between RD and D were observed by the end of the first work/rest cycle ($p<0.025$) and in cumulative body weight loss from the end of the first walk ($p<0.025$) (Figure 2, bottom panel).

Compared to cool water, total fluid intake decreased ($p<0.02$) with warm water by 40% in D (2.07 ± 0.38L) and by 50% in RD (1.04 ± 0.30L). When consuming warm water, RD lost 1.90 ± 0.22% body weight after the third hour and by the end of the sixth hour exhibited a total weight loss of 3.90 ± 0.41%, compared to 0.95 ± 0.22% at 3h and 2.33 ± 0.40% at 6h in D ($p<0.025$).

RD responded positively to flavoring by increasing fluid consumption from the onset (Walk 1) so that total 6h intake of warm (40°C) flavored water increased by 79% over plain warm water to 1.86 ± 0.22L, and body weight loss decreased to 3.30 ± 0.28% (Figure 3). Flavoring cool (15°C) water improved fluid intake (2.8 ± 0.2 L) and lessened body weight loss (2.0 ± 0.2 %) in RD although their 6h responses were not significantly different from the plain cool water trial. In D, flavoring either the warm or the cool water had essentially no effect on fluid intake or 6h body weight loss during the 6h heat exposure (data not shown).

Voluntary dehydration may further be evaluated in terms of percent rehydration [14]. During the cool water trial, D exhibited rehydration levels of 82.3 ± 2.1% as compared to cool flavored water (77.3 ± 5.4%), warm water (52.0 ± 8.1%) and warm flavored water (51.5 ± 8.3%). Thus, cooling the respective flavored or plain beverage produced significant ($p<0.025$) differences in rehydration for D, while flavoring itself apparently had no effects. For those reluctant to drink, cool flavored water again elicited a more favorable level of rehydration (63.7 $\pm$ 3.9%) than cool water (54.9 $\pm$ 2.3%), warm flavored water (41.0 $\pm$ 4.4%), or warm water (25.0 $\pm$ 7.4%). Therefore, while flavoring the drinking water only had a significant effect on rehydration for RD, cooling the drinking water enhanced rehydration for both groups.

Heart Rate and Rectal Temperature: No differences between D and RD were observed during the pre-exercise measures of HR and Tre during any of the four trials (Table 2). Likewise, 6h values were similar for both D and RD during comparative trials. However, significant increases in 6h HR and Tre values were observed in both groups when warm and warm-flavored water trials were compared to their cool and cool-flavored counterparts. Differences in Tre response became significantly different ($p<0.05$) during the fifth walk for both D and RD (data not shown) while HR responses remained similar until the final walk.

Blood Variables: Table 1 illustrates that there were no significant differences between pre-exercise blood or urine osmolarity, plasma electrolytes, hemoglobin and hematocrit, and urine specific gravity. During each trial, differences in serum variables were observed only when warm vs cool fluid trials were compared (Figure 4). Increases in plasma volume (%Δ PV) when consuming cool fluids and reductions in PV when consuming warm fluids were observed in both D and RD (Figure 5). While both groups were not significantly different from each other when consuming a particular beverage, significant ($p<0.05$) changes in 6h %ΔPV were observed when warm fluid trials were compared to cool fluid trials.

TABLE 2

EFFECTS OF COOLING AND/OR FLAVORING ON HR AND Tre RESPONSES

	pre-exercise HR (bpm)	6h exercise HR (bpm)	pre-exercise Tre (^{o}C)	6h exercise Tre (^{o}C)
DRINKERS				
Cool I_2 water	92[1]	137	37.00	38.21
	±6	±6	±0.09	±0.09
Warm I_2 water	89	151*	37.00	38.59*
	±4	±5	±0.09	±0.11
Cool I_2 flavored	87	140	37.00	38.33
	±5	±5	±0.05	±0.09
Warm I_2 flavored	89	149	37.07	38.70*
	±5	±7	±0.07	±0.11
RELUCTANT DRINKERS				
Cool I_2 water	79	126	36.97	38.16
	±4	±5	±0.07	±0.09
Warm I_2 water	83	140*	37.04	38.63*
	±7	±5	±0.06	±0.08
Cool I_2 flavored	86	131	36.99	38.13
	±7	±5	±0.05	±0.07
Warm I_2 flavored	85	148*	36.99	38.60*
	±4	±10	±0.21	±0.09

[1] Values represent mean ± SEM. For DRINKERS, n=9; RELUCTANT DRINKERS, n=5.

* Significant difference ($p<0.05$) between warm and corresponding cool fluid trial.

Questionaire Responses: When the Environmental Symptoms Questionaire (ESQ) was administered, eight subjects, five D and three RD, rendered their responses.

At the completion of the cool water trial, both D and RD rendered similar responses in their perception of many heat-related symptoms (Table 3). RD reflected their reluctance to drink by expressing a higher incidence of feeling extremely thirsty and warmer when compared to D.

During the warm water trial, both D and RD had similar response distributions when rating their degree of weariness and their perception of heat. RD perceived greater sensations of light-headedness, bodily aches and thirst relative to D. Compared to the responses elicited during the cool water trial, both groups rendered more complaints of light-headedness, stomach-discomfort and thirst when consuming warm water, and RD perceived a greater percentage of symptoms related to bodily aches and pains.

With flavored beverages (Table 4), ESQ responses indicated few differences between D and RD. Of notable interest is that both D and RD perceived a greater thirst with warm-flavored as opposed to cool-flavored water, and that RD drinking warm-flavored water perceived themselves as feeling warmer than when drinking cool flavored water. These results concur with measures of rectal temperature and fluid intake.

When asked to rate their subjective feeling of comfort by selecting the word or phrase that best described this perception after 6h in the heat (comfortable, slightly uncomfortable, uncomfortable, very uncomfortable, extremely uncomfortable), the following results were obtained from the fourteen subjects. Seventy-eight percent of D rated their warm flavored water trial between "uncomfortable" and "very uncomfortable", while 66% used this rating to describe their status after the warm water trial. For the flavored cool water and the cool water trials, 55% and 44%, respectively,

TABLE 3

ENVIRONMENTAL SYMPTOMS QUESTIONAIRE : EFFECTS OF TEMPERATURE[1]

Complaint	# of Questions	Group[2]	COOL (15°C) I_2 WATER %0	COOL %1,2	COOL %3	COOL %4,5	WARM (40°C) I_2 WATER %0	WARM %1,2	WARM %3	WARM %4,5
Weariness	6	D	37	40	3	20	40	23	3	32
		RD	33	39	17	12	33	28	16	16
Light-Headedness	5	D	76	24	0	0	60	28	4	8
		RD	80	20	0	0	47	13	33	7
Bodily aches	7	D	71	23	0	6	77	6	9	9
		RD	67	28	5	0	33	38	29	0
Temperature (Heat)	10	D	70	12	8	10	70	8	4	18
		RD	67	10	3	20	57	20	7	17
Thirst	5	D	56	36	4	4	44	32	4	20
		RD	47	33	7	13	40	20	13	20
Stomach-Related	7	D	97	3	0	0	83	3	3	12
		RD	95	3	0	0	67	23	10	0

Values indicate the percentage of responses from all the questions about a particular complaint for which group members rendered that numeric reply.

1 On a 6-point ESQ scale the following responses correspond to the numbers: 0, not at all; 1, slight; 2, somewhat; 3, moderate; 4, quite a bit; 5, extreme

2 D = DRINKERS, n=5; RD = RELUCTANT DRINKERS, n=3

TABLE 4

ENVIRONEMTAL SYMPTOMS QUESTIONAIRE: EFFECTS OF FLAVORING[1]

Complaint	# of Questions	Group[2]	15°C FLAVORED I_2 WATER %0	%1,2	%3	%4,5	40°C FLAVORED I_2 WATER %0	%1,2	%3	%4,5
Weariness	6	D	30	43	10	17	30	33	7	30
		RD	50	44	0	6	39	39	17	6
Light-Headedness	5	D	68	28	0	4	40	32	4	24
		RD	80	20	0	0	60	40	0	0
Bodily Aches	7	D	71	15	11	3	63	20	9	9
		RD	86	9	0	5	62	19	10	5
Temperature	10	D	74	4	4	18	70	4	8	18
		RD	67	20	3	10	60	7	13	20
Thirst	5	D	60	40	0	0	43	20	8	24
		RD	54	33	0	13	46	27	7	20
Stomach-Related	7	D	97	3	0	0	85	6	3	6
		RD	95	5	0	0	90	5	0	5

Values indicate the percentage of responses from all the questions about a particular complaint for which group members rendered that numeric reply.

1 On a 6-point ESQ scale the following reswponses correspond to the numbers: 0, not at all; 1, slight; 2, somewhat; 3, moderate; 4, quite a bit; 5, extreme

2 D=Drinkers, n=5; RD= Reluctant Drinkers, n=3

reported in the uncomfortable/very uncomfortable range. RD provided the lowest subjective ratings of comfort to their warm water trial, with 80% of subjects responding that they were either "uncomfortable" or "very uncomfortable". Warm flavored water and cool water trials produced responses of 60% and 40%, respectively, in this category, while cool flavored water elicited only 20% of responses in this range. The remainder of the responses ranked more favorably.

DISCUSSION

Similar to the variability in body weight loss observed by Rothstein [21], subjects drinking cool or warm water in this study demonstrated body weight deficits ranging from 0.5% to 4.95%. Such a variability in body weight loss has been previously noted in men working at different [2,22,23] and constant [24] levels of intensity in a hot environment. This range corresponded to mild dehydration (up to 5% loss in BW) as defined by Sohar [22], while Ladell [18] and Adolph [2] believed that dehydrations of 5-6% approached dangerous levels of water debt with respect to both mental and physical performance. The consumption of cool water can affect a differentiation in an apparently normal distribution of subjects performing constant work in a controlled environment into two distinct subpopulations: those who maintain body weight loss at less than 2% of initial (DRINKERS, D) and those when do not (RELUCTANT DRINKERS, RD) [24].

Fluid intake for the 6 work/rest cycles for D did not vary between flavored and non-flavored cool water (6h intake= 3.4 vs 3.3 L) or between flavored and non-flavored warm water (6h intake= 2.0 vs 2.1 L). Body weight losses also reflected minor differences; the 6h weight losses were 0.8% when drinking cool water versus 0.9% when drinking cool flavored water, and 2.3% when drinking warm water compared to 2.8% when drinking warm flavored water.

From these data we concluded that for those subjects defined as D, temperature of the beverage is the more important factor determining fluid consumption. A unique and suprising observation from this study was that flavoring had little effect on enhancing fluid consumption in D. In addition, over all four trials, D consumed 58% of their total fluids during the work periods. This agrees well with earlier findings by Hubbard et.al. [14] where 55% of the total fluid consumption occurred during the work cycles.

The importance of fluid temperature alone to maintain adequate levels of rehydration for D is further supported through ESQ responses where D expressed similar response distributions when given either warm or cool fluids. However, although consuming similar quantities of flavored and non-flavored water, D reported a slightly greater incidence of heat-related symptoms when water was flavored. When drinking cool water either no or very mild symptoms for most heat/exercise related complaints were reported by D. These observations agree well with earlier reports [19,25] wherein consumption of plain cool water exceeds that of flavored water when subjects must consume the same beverage for extended periods. In the present study, the higher incidence of complaints elicited by D when consuming warm water may have resulted from a reduced fluid intake or from consuming too much of an unpalatable beverage in the heat, or a combination of the two.

The subjective ratings rendered by D corresponded suprisingly well with their fluid intakes; flavored cool water was slightly less favored than cool water, and flavored warm water was rated slightly lower than warm water. This marginal preference for non-flavored beverages by D may have been due to the cumulative effect of the sweetness in the flavoring. While Sohar [22] observed that the most suitable beverage for copious consumption over a short period of time was one that was cool and sweetened, Rolls [20] and Adolph [2] noted that with time, subjects tired of a single flavoring and, when given the opportunity, readily returned to consuming plain cool water. In an earlier study, Hubbard et al. [14] observed an enhancement of group hydration as flavoring options were introduced and the temperature of the drink beverage was lowered, but their data were not evaluated in terms of drinkers and reluctant drinkers.

Alternatively, RD required either cooling or flavoring of the beverage to induce a higher fluid consumption. Fluid intakes increased from 1.0 L to 2.0 L when warm water was flavored, to 2.5 L when water was cooled, and to 2.8 L when cooled and flavored. It is noteworthy that body weight losses decreased correspondingly from 3.9% with warm water, to 3.3% with warm flavored water, to 2.5% with cool water, to 2.0% with cool flavored water. Hence, a positive alliesthesia toward cool flavored water was more pronounced in RD than in D, and reflected the increased importance of a behavioral component in stimulating drinking in this group.

Trends among RD were further maintained in the ESQ results. Warm flavored water (vs warm water) elicited responses of "not at all" for a greater percentage of symptoms for heat related disorders. Likewise when RD consumed cool flavored water (vs cool water), fewer reported complaints of weariness, thirst and bodily aches. Thus, by drinking greater quantities of flavored water at either temperature, RD apparently improved not only their physiological responses but also their psychological well being. These data agree well with results reported by Mack et.al. [18] who reported that voluntary fluid consumption and subjective rating of thirst were related to body weight loss during exercise.

The subjective ratings rendered by RD corresponded well to their changes in body weight loss and fluid consumption (flavored cool water > cool water > flavored warm water > warm water). Both physiological and psychological responses by RD demonstrated that this group required both cooling and flavoring of fluids in order to increase fluid intake and reduce dehydration and susceptibility to heat illness.

Two commonly accepted indices of heat stress are HR and Tre [2,16]. Our results concur with earlier studies [2,3,14,19,23] in which water temperature was seen to affect fluid intake, which in turn affected BW loss and hence dehydration, Tre and HR. Consequently, the more dehydrated the subjects, the higher their Tre and HR levels.

In spite of a greater fluid deficit in RD and contrary to the changes one would expect with greater dehydration, 6hr serum osmolarities and electrolyte concentrations during all four beverage trials were essentially unchanged in RD. The absence of increased serum electrolyte concentrations and osmolarity suggest that RD were able to protect plasma volume by drawing on body water pools during a time of apparently reduced total body water. Thus, RD were able to maintain plasma osmolarity despite a total body water deficit. Greenleaf and Sargent [12] postulated that this might be a possible physiological adaptation to a state of dehydration. In support of this hypothesis are the 6h plasma volume changes which show that compared to D, RD had a greater increase in plasma volume when drinking cool beverages and a lesser reduction in plasma volume when consuming a warm beverage. These trends suggest efficient regulation of plasma constituents during dehydration in RD.

In conclusion, this study demonstrated that in a population comprised of individuals defined as drinkers and reluctant drinkers, voluntary dehydration can be reduced by increasing the palatability of drinking water. For drinkers, cooling the drinking water (positive alliesthesia) produced the best response in counteracting dehydration, while for those subjects categorized as reluctant drinkers, either cooling or flavoring produced favorable responses.

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Disclaimer

The views of the authors do not purport to reflect the positions of the Department of the Army or the Department of Defense. Human subjects participated in this study after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 in Use of Volunteers in Research.

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Figure Legends

Figure 1. Frequency distribution of 6h precent body weight loss in 14 subjects during the cool water trial.

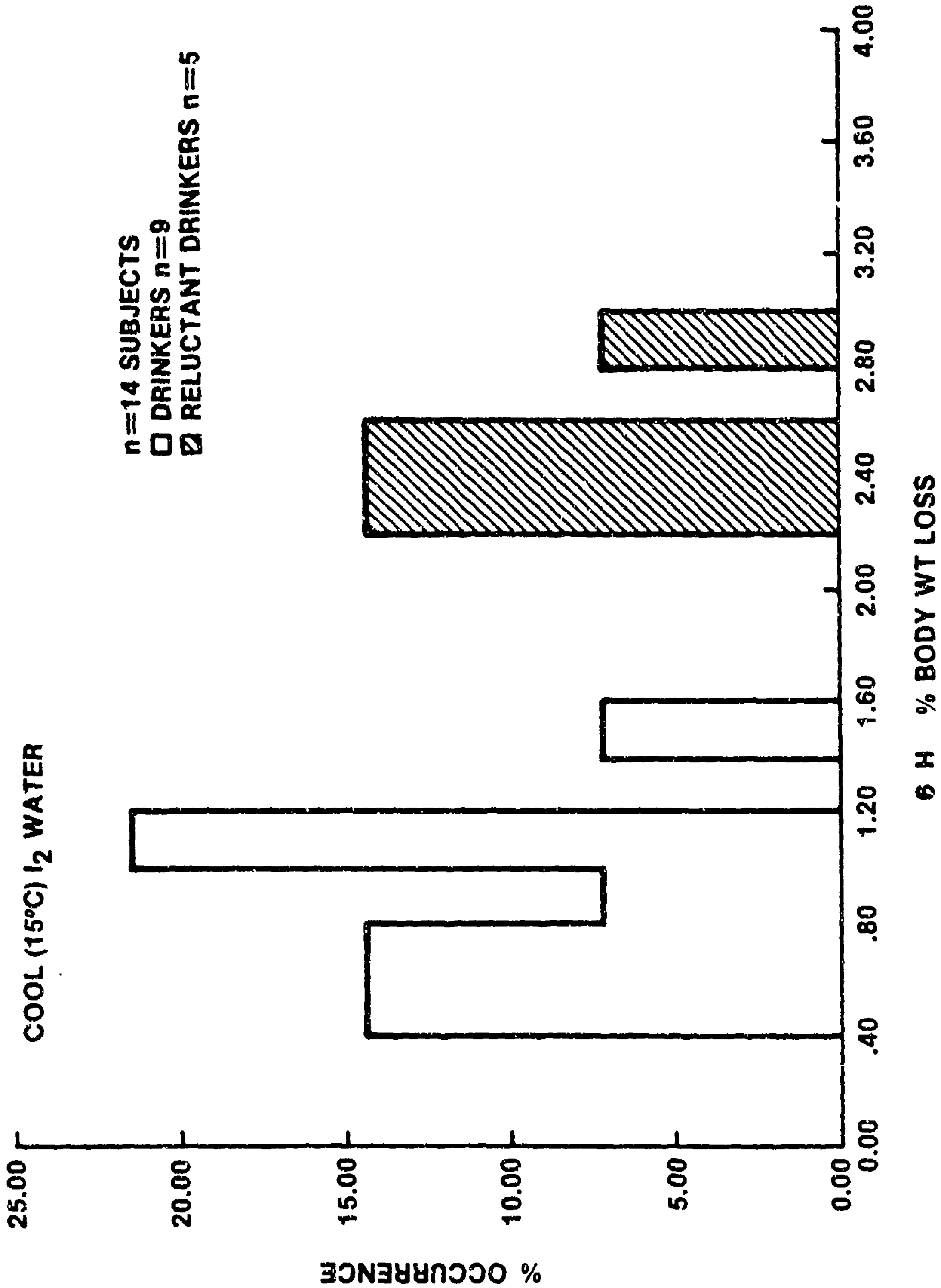
Figure 2. Cumulative fluid intake (ml) (top panel) and body weight loss (%) (bottom panel) for five (5) RELUCTANT DRINKERS and nine (9) DRINKERS during the 6 hour cool (15°C) and warm (40°C) water trials.

Figure 3. Comparison of cumulative fluid intake (ml) (top panel) and percent body weight loss (bottom panel) for five (5) RELUCTANT DRINKERS during the plain and flavored warm (40°C) water trials.

Figure 4. Average (±SEM) 6 hour changes in plasma osmolarity (Posm), sodium (PNa+) and potassium (PK+) for DRINKERS and RELUCTANT DRINKERS during the four beverage trials. Indicates the mean is significantly different ($p<0.05$) between cool and warm beverage trials.

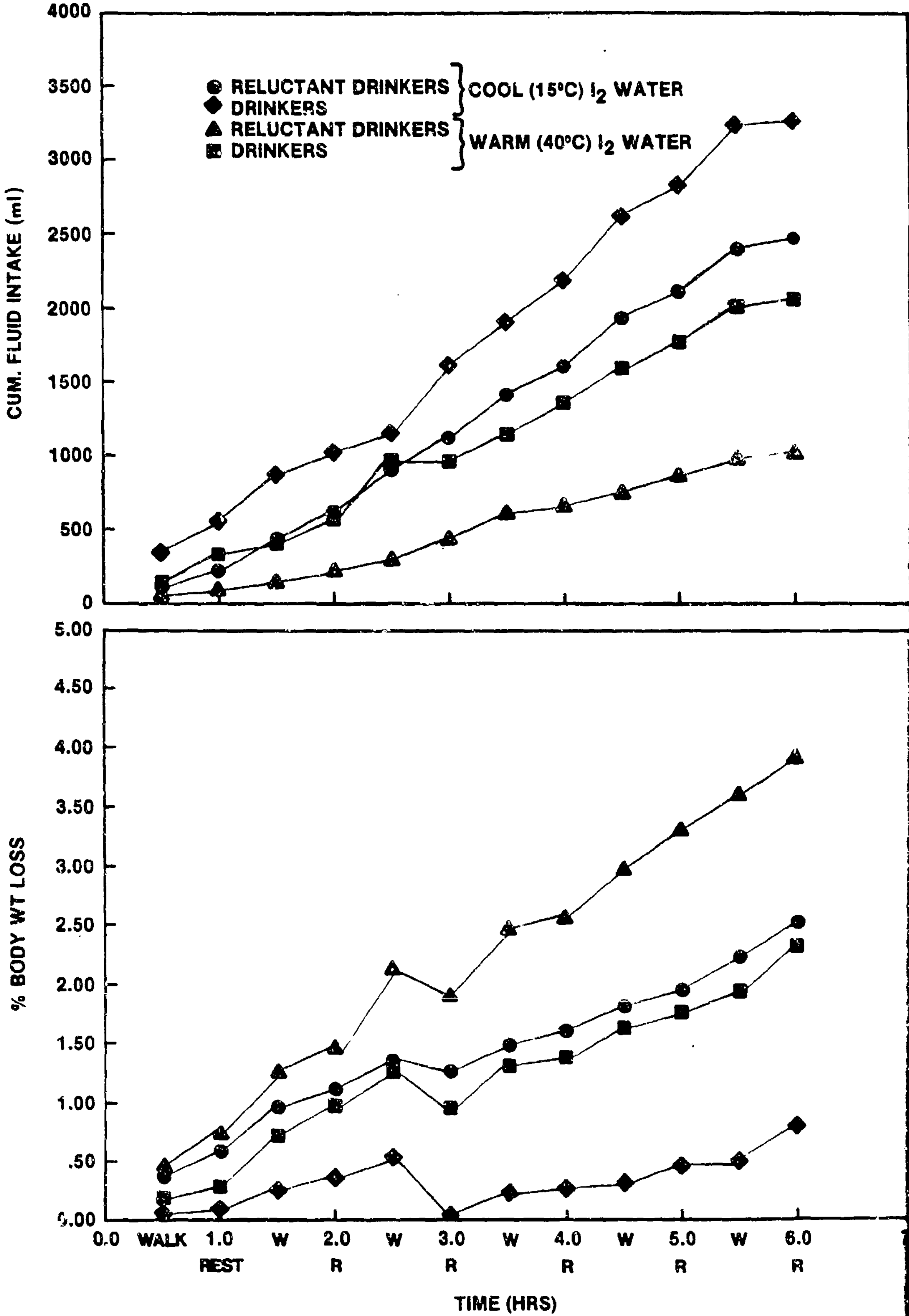
Figure 5. Average (±SEM) 6 hour changes in plasma total protein, hematocrit and plasma volume for DRINKERS and RELUCTANT DRINKERS during the four beverage trials. ★Indicates that the mean is significantly different ($p<0.05$) between cool and warm beverage trials.

FIGURE 1



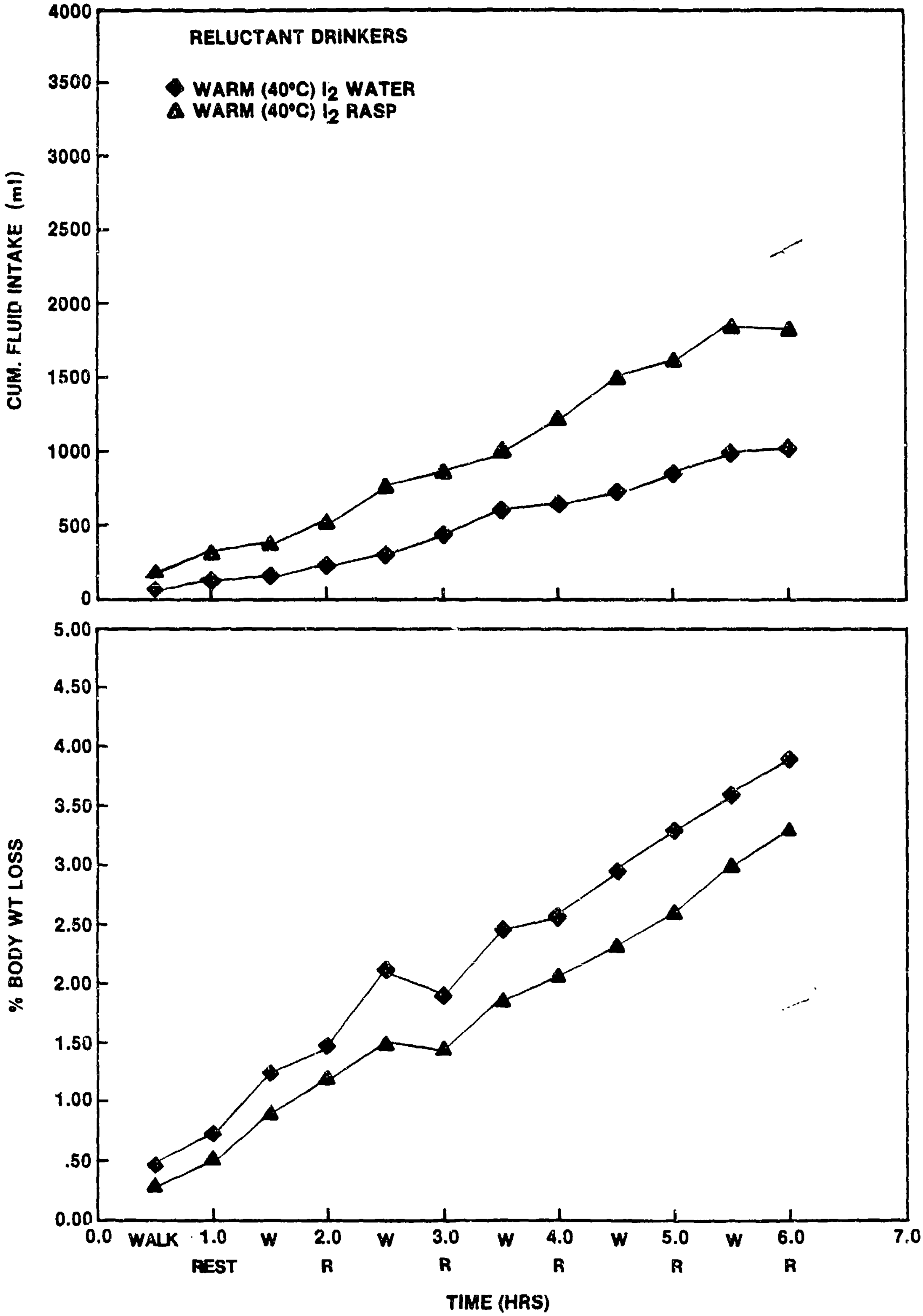
COOL (15°C) I_2 WATER
n=14 SUBJECTS
□ DRINKERS n=9
▨ RELUCTANT DRINKERS n=5
% OCCURRENCE
25.00
20.00
15.00
10.00
5.00
0.00
0.00
.40
.80
1.20
1.60
2.00
2.40
2.80
3.20
3.60
4.00
6 H % BODY WT LOSS

FIGURE 2



RELUCTANT DRINKERS
DRINKERS
COOL (15°C) I_2 WATER
RELUCTANT DRINKERS
DRINKERS
WARM (40°C) I_2 WATER
CUM. FLUID INTAKE (ml)
4000
3500
3000
2500
2000
1500
1000
500
0
% BODY WT LOSS
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
.50
0.00
0.0
WALK
1.0
REST
W
2.0
R
W
3.0
R
W
4.0
R
W
5.0
R
W
6.0
R
TIME (HRS)

FIGURE 3



RELUCTANT DRINKERS
WARM (40°C) I2 WATER
WARM (40°C) I2 RASP
CUM. FLUID INTAKE (ml)
4000
3500
3000
2500
2000
1500
1000
500
0
% BODY WT LOSS
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
.50
0.00
0.0
WALK
1.0
REST
W
2.0
R
W
3.0
R
W
4.0
R
W
5.0
R
W
6.0
R
7.0
TIME (HRS)

FIGURE 4

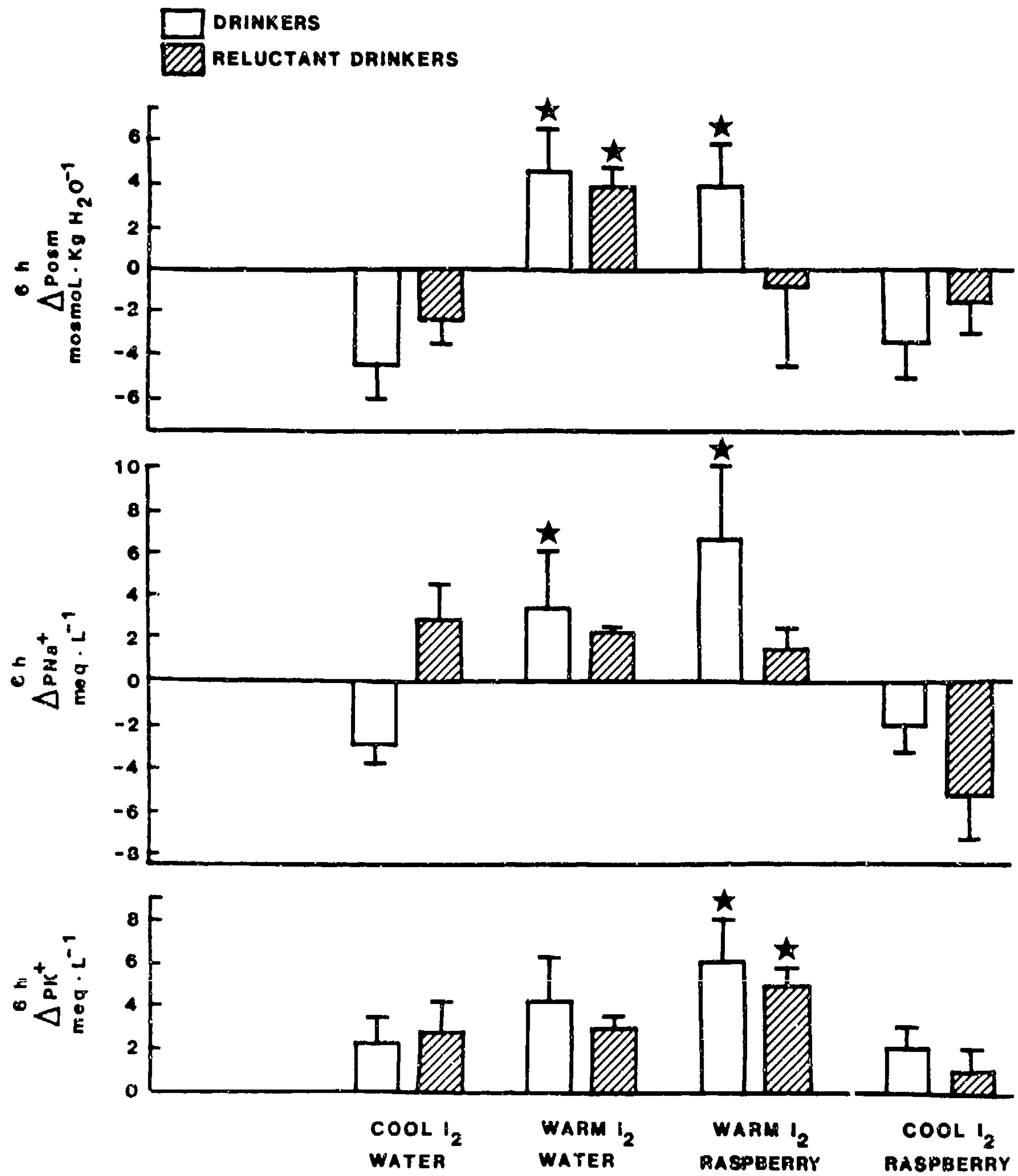
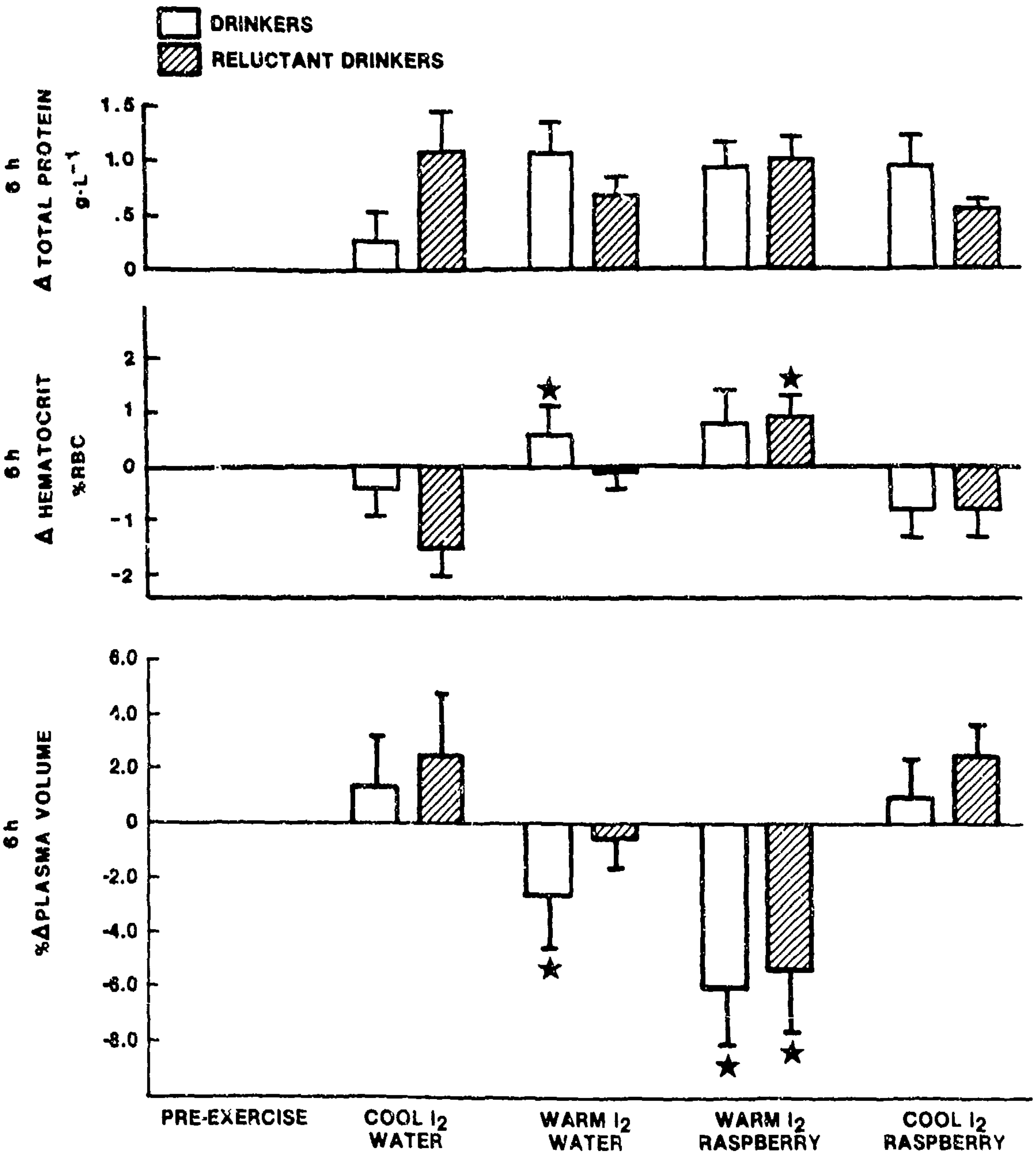

DRINKERS
RELUCTANT DRINKERS
6 h
ΔPosm
mosmoL · Kg H2O-1
6
4
2
0
-2
-4
-6
10
8
6
4
2
0
-2
-4
-6
-8
6 h
ΔPNa+
meq · L-1
8
6
4
2
0
6 h
ΔPK+
meq · L-1
COOL I2
WATER
WARM I2
WATER
WARM I2
RASPBERRY
COOL I2
RASPBERRY

FIGURE 5


DRINKERS
RELUCTANT DRINKERS
6 h
Δ TOTAL PROTEIN
g·L⁻¹
1.5
1.0
.5
0
6 h
Δ HEMATOCRIT
%RBC
2
1
0
-1
-2
6.0
4.0
2.0
0
-2.0
-4.0
-6.0
-8.0
6 h
%ΔPLASMA VOLUME
PRE-EXERCISE
COOL I2
WATER
WARM I2
WATER
WARM I2
RASPBERRY
COOL I2
RASPBERRY